EFFECTS OF SPORTSWEAR DESIGN ON THERMAL COMFORT

M. J. ABREU[1], A. CATARINO[1]; C. CARDOSO[2];E. MARTIN[3]
[1] Textile Engineering Department, University of Minho, Guimarães (P)
[2] Center for Textile Science and Technology, University of Minho, Guimarães (P)
[3] Textiltechnologie, Fachhochschule fuer Technik & Wirtschaft, Reutlingen (D)
josi@det.uminho.pt

ABSTRACT
Several technical developments in the sportswear clothing industry resulted in the use of functional textiles for highly-specialized performances in all kind of sports.
This paper reports on an experimental investigation on the effects of garment design in thermo-physiological body comfort, measured in terms of clothing insulation for a specific outdoor sport - rowing.
The thermal manikins have been used to measure clothing insulation and to evaluate the thermal comfort. Thermal manikins provide a good estimate of the total dry heat loss from the body and the distribution of heat flow over the body surface. In a standard environment, these measurements can be used to describe the thermal characteristics of clothing.
Testing of sportswear clothing made of different fibers and garment designs, namely by varying knitting structures, show the possibilities of influencing thermal comfort, especially thermal insulation.
The evaluation and understanding of the thermal effects of garment design and fabric materials is important for the development and optimization of functional garments.
Therefore, the final aim of this paper is to study and validate the thermal comfort behaviour of active sportswear for rowing using single and multiple knitted zones in the garment design and considering also differences in material composition through thermal manikin measurements.

KEYWORDS: Thermal comfort, garment design, knitting structure, thermal manikin

INTRODUCTION

As more people participate in outdoor activities, the active sportswear with new thermal properties is a new type of clothing to be investigated and to determine their thermal comfort.
Rowing is an outside water sport and the rower can be exposed to splash water, rain, sun and wind. The clothes play an important role for the rower's comfort and should protect him from all environmental impacts, namely contaminated water which can result in skin problems. Furthermore they may affect the performance and efficiency of the athlete.
During rowing activity, the athlete is seated and slides together with a specially designed sliding seat. The clothes should cover the renal area and it is very important that the clothes don't get entangled with the shaft.
In a normal situation, human beings restore a correct balance of heat exchange, modifying the environment. However, outdoor activities are more demanding in terms of thermal balance, and the ability of recovering the thermal balance is more dificult to achieve. For that reason, active sportswear should provide sufficient heat transfer for the skin temperature remains within comfortable range.
Comfort is thus essential for an athlete, since it may avoid the latter from using more reserves from his body in order to restore the balance of heat exchange with the external environment.[1,2].

Thermal Comfort

The thermal comfort is defined as the condition of mind which expresses satisfaction with the thermal environment [3]. It is a pleasant state of a human being that is psychologically, physiologically and physically in harmony with the surrounding environment.
Thermal interaction between man and environment is highly complex, because the person's perception of thermal comfort is affected by several parameters, such as air temperature, air movement (speed), humidity, clothing, activity level, mean radiant temperature (the average temperature of the walls, floor, windows) and many other factors. So, thermal comfort stands for the proper relationship between body heat production and loss. For that reason, thermal manikins can serve research and development in this field, because they are widely used for analysing the thermal interface of the human body and its environment [1,2].

Thermal manikins

Thermal manikins have served research and development purposes for more than 60 years. They are widely used for analysing the thermal interface of the human body and its environment. [4]

Thermal manikins provide a good estimate of the total dry heat loss from the body and the distribution of heat flow over the body surface. In a standard environment, these measures can be used to describe the thermal characteristics of clothing. [5]
The thermal manikin is an instrument for measuring the thermal insulation of garments and clothing ensemble. They are considered to be one of the most useful tools for evaluating thermal comfort of overall clothing systems. In comparison to other methods for measuring thermal properties of clothing, thermal manikin studies allow to investigate fully assembled clothing in the way these garments are supposed to be used (multi-dimensional), however without any influence of subjective interpretation of human testing or simply physical testing of the materials (bi-dimensional).

EXPERIMENTAL APPROACH

Tested Material

Several long-sleeved seamless sports shirts for rowing activity were tested which are briefly described in Table I. From a base type shirt, identified as type, B and C, made of more than one knitted structure, variants were produced using only one kind of knitted structure in order to understand if the combinations of raw material and knit structure have an influence in heat loss. All the shirts were produced with the same conditions, on seamless knitting machines, with the exception of the raw material and the knitted structure.

TABLE I. Description of the shirts include in the test trial.

Type	Composition	Knitting structure
A	100 % cotton	Single jersey (173,8 g/m^2)
B	60% PA black 35% PES grey 5% EL	knit-float combination/single jersey (171,4 g/m^2)
C	60% PA black 35% PP grey 5% EL	Jersey/knit-float combination (195,9 g/m^2)

In figure 1 is represented the 100% cotton basic jersey shirt. The shirt is designed with conventionally sewed side seams and round-necked.

FIGURE 1. Basic shirt 100% cotton (Type A).

In figure 2 are represented the three combinations made for shirt type B, that consists in three different knitted structures: B-1 (knit-float combination), B-2 (knit-float combination) and B-3 (single jersey). Shirt B combines these strutures in different areas, while shirts B-1, B-2 and B-3 are made with only one kind of structure.

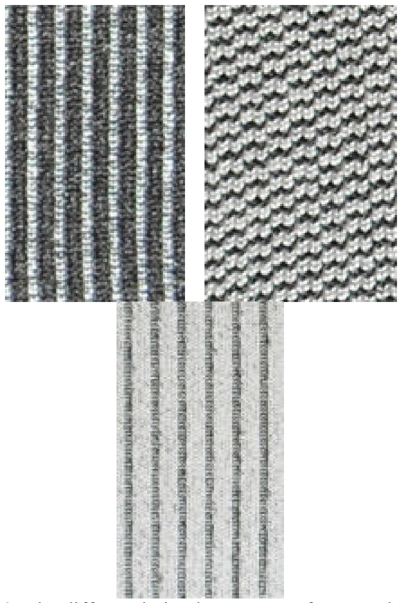

FIGURE 2. The different knitted structures of type B shirts: left: B-1; center: B-2; right B-3.

In figure 3 are represented three combinations used on shirt type C, that consists in three different knit structures C-1 (single jersey), C-2 (single jersey) and C-3 (rib) located on varying parts of the garment . The base shirt type C was produced using the three strutures in which structure C-1 is predominant.

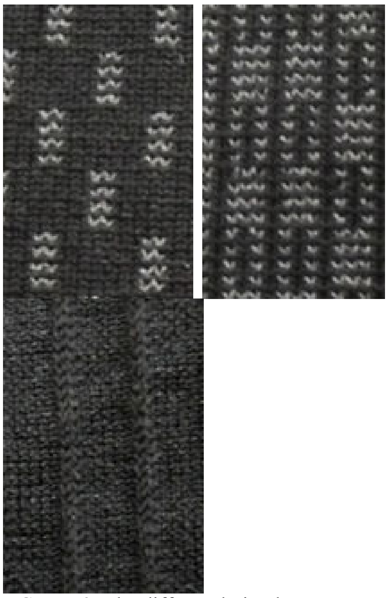

FIGURE 3. The different knitted structures of type Cshirt:left: C-1; center: C-2; right C-3.

In figures 4 and 5 are represented the simple knitting structures used in the entire area of the shirts.

FIGURE 4. Shirt Type B-1 (175,9 g/m^2), B-2 (192,0 g/m^2), and B-3 (200,6 g/m^2).

The material composition of sample-shirt B-1 is 60% polyamide as a black yarn, 35% polyester as a grey yarn and 5% elastane as a transparent yarn. The structure is a knit-float combination, also known as false rib, in which the floating loop of polyester yarn is in the technical back of the shirt, whereas the polyamide is predominant on the technical right side of the fabric.
The material composition of sample B-2 is 60 % polyamide (black), 35% polyester (grey) and 5% elastane (transparent). The polyester is predominant on technical front side and polyamide on technical back. This is the reason why the sample’s color is grey. The shirt uses the same knitted structure and design as B-1 resulting in floating threads of polyamide on the inside.

Sample B-3 consists out of 60% polyamide (black), 35% polyester (grey) and 5% elastane. The knit structure is single jersey, where polyester is predominant on technical front and polyamide on the inside of the garment, .

FIGURE 5. Shirt Type C-1 (183,2 g/m^2), C-2 (172,9 g/m^2), and C-3 (177,0 g/m^2).

The material composition of sample C-1 is 60% polyamide as a black yarn, 35% polypropylene as a grey yarn and 5% elastane. It is a single jersey structure.
On the technical front side of the fabric the polyamide is predominant; however the inside appears grey because of the predominant polypropylene yarn.
The material composition of sample C-2 is comparable to the other samples in this group: 60% polyamide as a black yarn; 35% polypropylene as a grey yarn and; 5% elastane. The structure is single jersey where polypropylene predominates on the technical front side.
The material composition of sample C-3 is 60 % polyamide as a black yarn, 35 % polypropylene as a grey yarn and 5 % elastane. The structure C-3 appears more often on the right side.

Test equipment

The thermal manikin used in this research study is installed in the research laboratory of the Textile Engineering Department of the University of Minho in Portugal.
This thermal manikin use the same basic concept in that the heating power required to keep the manikin surface at a constant temperature is measured and used to correlate with thermal comfort.
The thermal manikin, called “Maria” (Figure 1), has a woman’s body; its size and configurations are similar to an adult woman.
The manikin is divided in 20 thermally independent sections and only sense dry heat transfer. “Maria” achieves a body temperature distribution similar to

a real person. The mean skin temperature of "Maria" can be adjusted.

All tests were conducted controlling the defined air temperature and air humidity. There was a dry heat flow from the manikin's skin surface area through the clothing into the ambient air, which was measured after steady-state conditions have been reached. From this heat flow, which is related to the nude manikin's body surface area, the active sportswear thermal insulation is then calculated, considering the temperature difference between the manikin's skin surface and the ambient air.
In human sciences, the unit of thermal insulation used is the Clo. This unit does not measure the material insulation, but the insulation provided to the whole person.
The manikin was slightly above the floor (0,10 m) in a standing position during the measurements. [1,2,6,7].

Test Methods
The active sportswear's were tested according to ISO 15831. The test time of each measurement was 60 minutes, during which the skin temperature and heat loss were monitored every minute. At the end of each measurement the heat loss was obtained and recorded to the computer.
The manikin was kept stationary standing position, with its legs straight and the arms hanging straight without movement. The skin temperature was set and during the test period maintained at 33 ± 0.2°C. The total clothing insulation (I_T), i.e. the insulation from the skin surface to the environment (1) was calculated using the global method under static conditions where the area-weighted of all heat losses and skin temperatures of each body part are summed up before the insulation is calculated, like if it was a manikin with only one segment. This is the general formula for defining the whole body resistance [8]:

$$I_T = \frac{\sum_i (f_i \times t_{si}) - t_0}{\sum (f_i \times \dot{Q}_{si})} \qquad (2)$$

The effective clothing insulation (I_{cle}), consisting of the difference between I_T and I_a are calculated by the equations, considering I_a is measured by operating the manikin nude:

$$I_{cle} = I_T - I_a$$

Where:

f_i = relationship between the surface area of the segment ***i*** of the manikin (A_i) and the total surface area of the manikin A (fi=Ai/A).

t_0 = : [ºC]

f_i = re[ºC]

$\dot{Q}_{si}$ = sensible heat flux of the manikin obtained by area

TEST RESULTS AND ANALYSIS

Heat loss
The following figures reveal the test values and first step to analyse the obtained results.

Figures 6, 7 and 8 show the heat loss from the nude manikin in comparison to the manikin dressed with the basic shirt A, the base type shirt B and C and the shirt types B-1, B-2, B-3, C-1, C-2 and C-3.

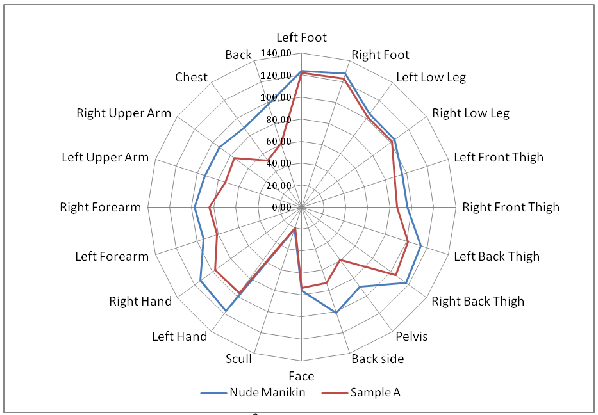

FIGURE 6. Heat loss in W/m^2 from the thermal manikin with shirt type A.

The nude manikin possesses the most significant heat loss. As expected, there is no significant difference between the unclothed parts like feet and legs. On the other hand, the clothed parts like chest, pelvis, back, upper arms and forearms show significant differences in heat loss. Even on partly covered body segments like thighs and hands, heat loss of the clothed manikin shows lower values.

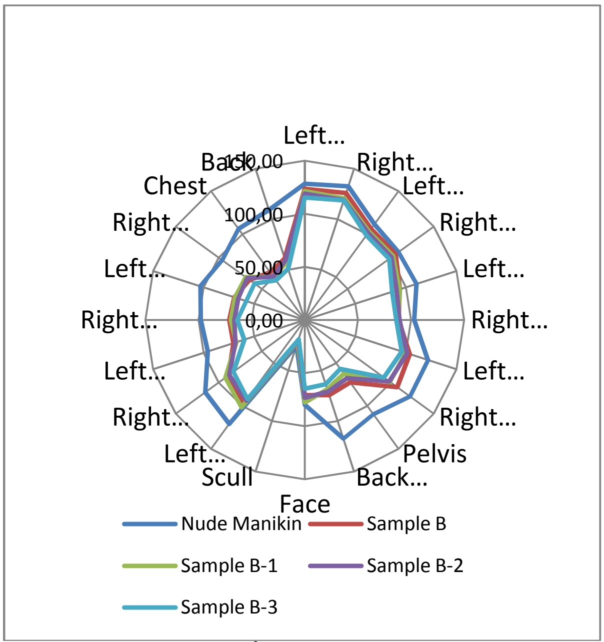

FIGURE 7. Heat loss in W/m^2 from the thermal manikin with simple and combined knitted structures type B.

Figure 7 presents the heat loss for shirts of type B. The sample B-3 shows in most of the segments the lowest heat loss of this testing series. Mainly the heat losses from backside, pelvis, upper arms, forearms and hands are considerably different from the other testing samples.

Especially sample B with the combined knitting structures shows, except for the nude manikin, the highest heat loss generally on the backside, pelvis, and chest.

However the differences between the shirt samples are marginal and the unclothed parts e.g. face and right foot show little differences as well.

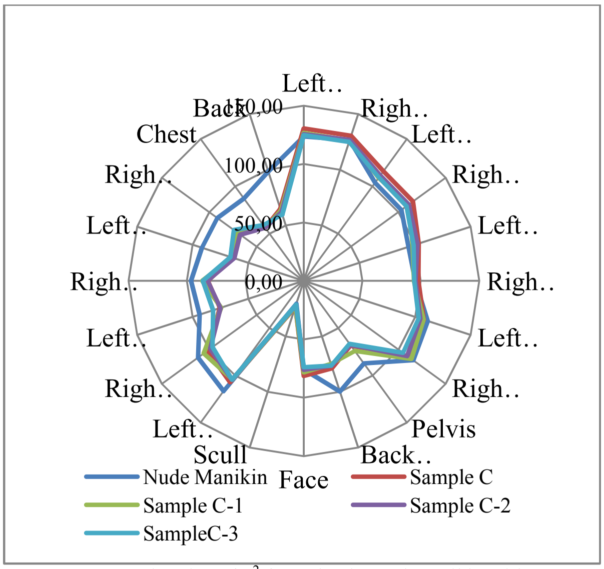

FIGURE 8. Heat loss in W/m^2 from the thermal manikin with simple and combined knitted structures type C.

Figure 8 illustrates the results for heat loss when the thermal manikin is dressed with the different C – type shirts. There is no denying the fact that the nude manikin has again the highest loss. It is not obvious that one of the samples shows much lower losses in heat than others.

On the back, sample C-3 shows the lowest loss, however on the forearms it shows the highest.

Clothing Insulation

In the figures 11 and 12 below one can observe the total thermal insulation (I_T) and the effective clothing insulation (I_{cle}) obtained for the shirts under investigation.

Figure 11 shows the total thermal insulation of the nude manikin and the manikin wearing the different samples. It is obvious, that the nude manikin tests always show the lowest insulation.

Basic shirt A presents similar results than shirts type B and C.

Also between the "mother shirts" and the "daughter shirts" didn´t exist significant differences.

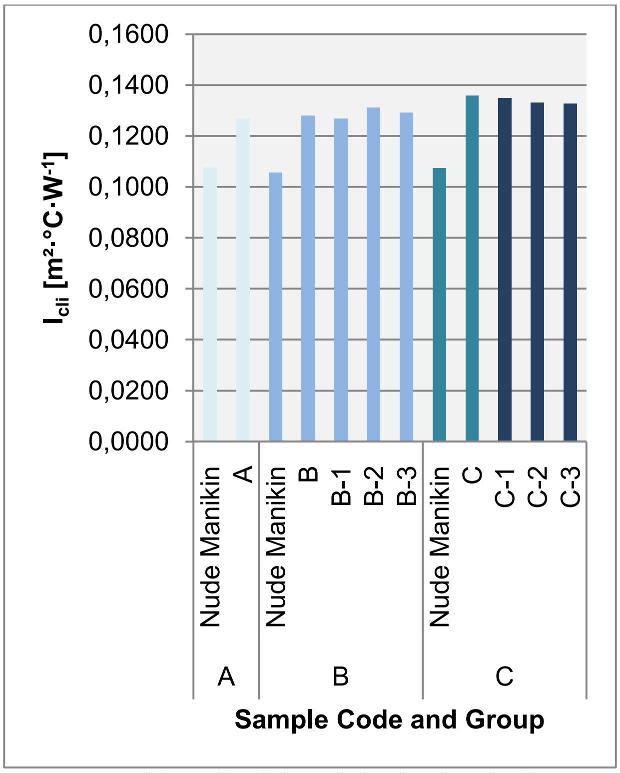

FIGURE 9. Total thermal insulation-calculated results using the global method.

It can be observed that the shirts show the same behavior in both figures, although decreasing when you subtract the thermal insulation of the air layer, resulting the effective clothing insulation (Figure 10).

The reduction of the insulation because of the elimination of the air layer insulation for the basic shirt type A is around 85% and for the mother shirts B and C respectively around 82% and 79%.

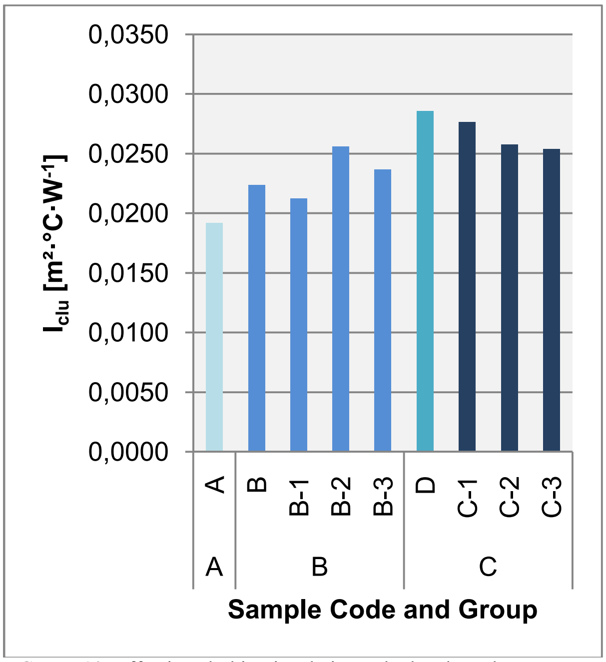

FIGURE 10. Effective clothing insulation-calculated results using the global method.

CONCLUSIONS

The main conclusion about our test trial is that all shirts showed a thermal insulation of more than 0,019 $m^2 \cdot °C \cdot W^{-1}$ or 0,124 clo.

Whereas the basic cotton shirt A shows the lowest insulation value, sample B shows nearly the same insulation and sample C provides the highest amount of insulation of all base shirts.

There is now evidence that the shirts with the multiple knitting structures can provide a higher insulation than the shirts with the single knit structure.

In group C, the sample with the multiple knitted zones shows the highest insulation, whereas in group A the base shirt shows one of the lowest insulation capability.

The fact that no shirt shows far more insulation than all others does not simplify the interpretation of the obtained data.

From the results obtained there is no clear evidence, that different structures nor different weights may led to clearly different insulation values.

The difference between type B and C may consist on the different material composition. The fiber polypropylene (type C) in comparison with polyester (type B) has better thermal insulation behaviour.

As future developments on this project, the team is studying the effect of water repellent products on these same garments in order to evaluate the influence on heat loss, as a second step for a contribution to a shirt capable of protecting the rower's skin from contaminated water, rain and wind, but at the same time allowing the rower's thermal balance.

REFERENCES

[1] Abreu, M. J., "Validation of the thermal comfort behaviour of active wear through thermal manikin measurements", 2nd International Scientific Conference Textiles of the Future, Kortrijk, Belgium, November 2008.

[2] Abreu, M. J., "An investigation of the thermal comfort behaviour for active wear using a thermal manikin", 7th International Thermal Manikin and Modelling Meeting, Coimbra, Portugal, September 2008.

[3] ISO 7730, Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria; ISO, 2005.

[4] Holmer, I., "Thermal manikin history and applications", *European Journal of Applied Physiology*, Vol. 92, 6, (2004) 614-618.

[5] Wyon, D.P., "Use of thermal manikins in environmental ergonomics", *Scandinavian Journal of Work, Environment& Health*, (1989).

[6] Abreu, M. J.; Braga, I.; Duarte, F., "Simulating human physiological response with a thermal manikin testing different non active medical devices", *Journal Materials Science Forum,* Vol. 636-637(2010), 36-41.

[7] Abreu, M. J. et al; "Comparison between human physiological response of different diabetic socks", 41st International Symposium on Novelties in Textiles, Ljubljana, Slovenia, May 2010.

[8] Oliveira, A. V. et al, "Measuring thermal insulation of clothing with different manikin control methods. Comparative analysis of the calculation method", *Book of Proceedings*, 7th International Thermal Manikin and Modelling Meeting, Coimbra, Portugal, September, 2008.